PAPER • OPEN ACCESS

Main features of distributions of the magnetic flux leakage fields of defects different shapes

To cite this article: A P Novoslugina and Ya G Smorodinskii 2019 *J. Phys.: Conf. Ser.* **1389** 012037

Main features of distributions of the magnetic flux leakage fields of defects different shapes

A P Novoslugina[1,*] and Ya G Smorodinskii[1,2]

[1]M.N. Mikheev Institute of Metal Physics, Ural Branch of Russian Academy of Sciences, 620108, Ekaterinburg, Russia

[2]Ural Federal University named after the first President of Russia B. N. Yeltsin, 620002, Ekaterinburg, Russia

*Corresponding author: novoslugina@imp.uran.ru

Abstract. The features of topography of the magnetic fields of various defects are considered using the finite element method (FEM). The distinctive attributes of these defects are identified and some recommendations are given on determining different types of defects. It is shown that extremes of the normal component of the magnetic field created by defects are closely connected with an orientation and an angle of inclination of a defect in a plate. An approach for estimating this angle of inclination of surface defects and extended subsurface defects is proposed.

1. Introduction

Measuring and calculating the magnetic fields inside and outside of ferromagnetic objects are the actual problems for magnetic non-destructive testing (NDT), which is used to determine the existence of defects and their parameters. NDT consists of different methods, one of which is a magnetic flux leakage (MFL). Each of approaches for analyzing the MFL fields of defects has some advantages and limitations. Using magnetic objects made of different steel grades in production complicates the solution of the inverse problem of determining the parameters and dimensions of defects. The main problem in calculation of fields consist in the nonlinear dependences of the magnetization M and magnetic permeability μ. Choosing the best method for solving the problems connected with the evaluation of dimensions of defects in materials, one should take into account magnetic properties of a substance (μ), all the assumptions connected with boundary conditions, the required accuracy, rapidity and laboriousness of calculations and the consistency with experimental data.

Using modern software for analyzing MFL fields allows us to simulate defects of various forms, which differently oriented in space and located at different depths [1–3]. The main difficulties, features and errors of using programs based on the finite element method (FEM) are reviewed in [4]. To determine defects in practice, one has to know the specific features of the distribution of MFL fields close to the defects of various shapes and sizes.

2. An approach for evaluating a defect orientation

In our work, we considered MFL fields of three classes of defects: inclusions, surface and extended subsurface defects.

Some features in distributions of MFL fields of defects close to a plate from different steel grades (10, 20, 30HGSA, 36G2S, H70) are reviewed within the two-dimensional model of defects (figure 1). A thickness of a plane-parallel plate was chosen 12 mm due to the fact that this size is one of the most common sizes of wall thickness of pipes, used in industry. For this model, the value of the external magnetization field H_0 was 5000 A/m.

In practice there is always a small gap between the sensor and the object, therefore, the tangential and normal components of the magnetic fields were calculated with a gap y = 0.25 mm above the plate surface. If a gap increases, the picture of the behavior of the magnetic components will not change, but the magnitudes of these components of the magnetic fields will decrease.

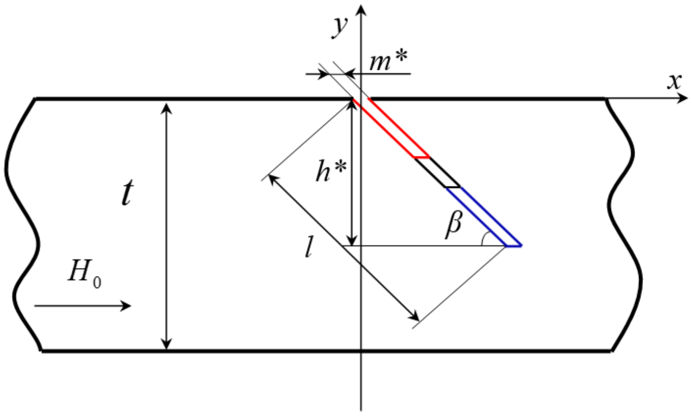

Figure 1. A plane-parallel plate with a surface defect.

The surface inclined defects, located in the plane-parallel plate, were examined in order to establish how the angle of inclination influences on the magnetic fields of defects. It was established that the direction of translocation of the graphs of the magnetic components was related with the value of an angle and the direction of inclination. Based on the obtained data, an approach for estimating the angle of inclination of a surface defect was proposed.

First of all it is necessary to determine at which point the tangential component H_t of the magnetic field reaches its maximum value**.** The center of a relative coordinate system will pass through this point. For each identified defect there will be its own coordinate system. Figures 2 and 3 depict these systems with dotted lines. The operation of positioning the origin of coordinates is necessary, as on the manufacture in the process of continuous monitoring of defects in different materials, there is no reference to the coordinate system, which is displayed during software calculations.

This technique is connected with the measurement of the x coordinate between the maximum of the normal component Hn_1 and the minimum of the normal component Hn_2 of the magnetic fields (extremes) — l_1 and l_2 (figure 2, 3).

For example, for the surface defect (h* = 6 mm), located with a slope to the right (angle β = 30°): l_1 = 0.41 mm and l_2 = 0.31 mm. For the same defect, inclined to the left: l_1 = 0.23 mm and l_2 = 0.27 mm. For the surface defect (h* = 11 mm), located with a slope to the right (angle β = 30°): l_1 = 0.40 mm and l_2 = 0.24 mm, etc.

So if $l_1 > l_2$, a defect will be inclined to the right, and if, on the contrary, $l_1 < l_2$ - to the left. In the case when $l_1 = l_2$ a defect will be non-inclined.

In practice, this technique will depend on the accuracy of calculations and measurements, because the difference in the values of l_1 and l_2 is insignificant.

The methodological approach for determining the direction of inclination of a defect, described for the surface defects, is also applicable for the extended subsurface defects. Figure 4 shows a model for comparing the fields of defects (k = 1 mm, m = 2 mm), arranged parallel to the boundary of the plate and with a slope (angle β = 45°).

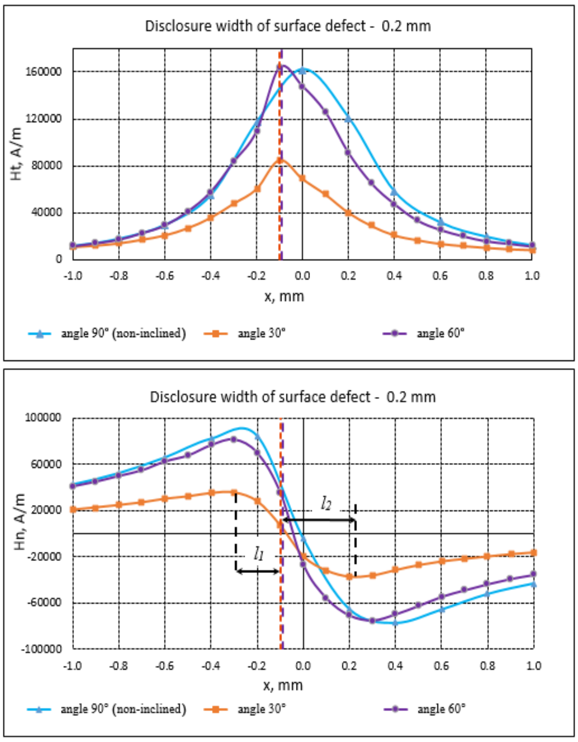

Figure 2. MFL fields close to non-inclined (90°) defects and defects inclined to the left (angle is 30° and 60°). All defects are located on the depth 6 mm.

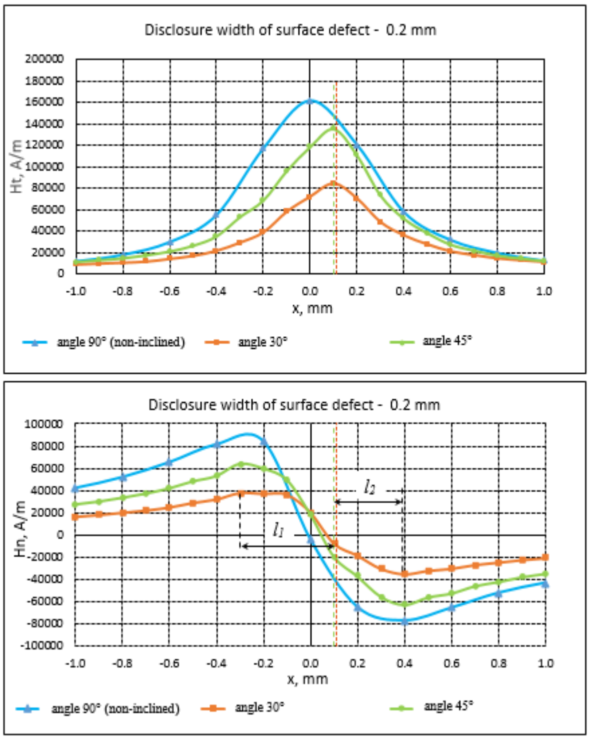

Figure 3. MFL fields close to non-inclined (90°) defect and defects inclined to the right (angle is 30° and 45°). All defects are located on the depth 6 mm.

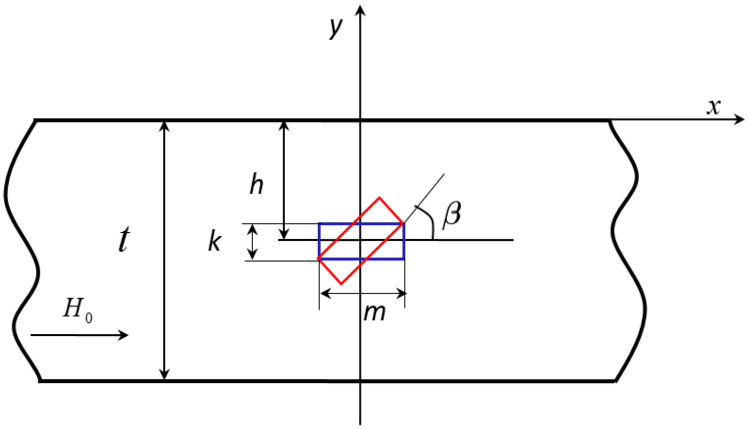

Figure 4. A plane-parallel plate with extended subsurface defects.

Having determined $l_1 = 1.9$ mm, $l_2 = 2.8$ mm for the subsurface inclined defect (figure 5), it can be assumed that it is inclined to the left and it is this true (figure 4). The direction of inclination of surface defects and also extended subsurface defects can be determined using this approach.

Such extended defects elongated along the x axis from 3 bis 20 mm (size was fixed along y axis and was 1 mm) were considered in [5]. The fields of defects increased as their lengths enlarged up to 10 mm, and then there was a slight decrease in the maximum values of the tangential components of the magnetic fields, which remained constant for a certain segment, forming a horizontal plateau (figure 6).

The modeling of inclusions, using the same initial conditions, was considered in details in [6]. The values of the tangential and normal components of magnetic fields of the surface defect are noted to be several times greater than such values of fields of the defect in the form of inclusion, even if its area is slightly larger than the area of the defect in the form of inclusion.

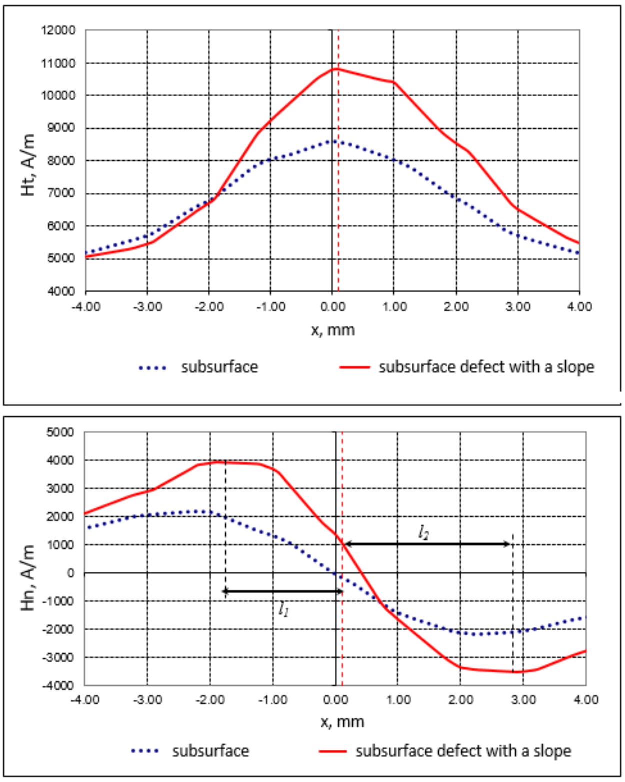

Figure 5. The comparison of the magnetic fields of defects located parallel to the boundary of the plate and with a slope (β = 45°).

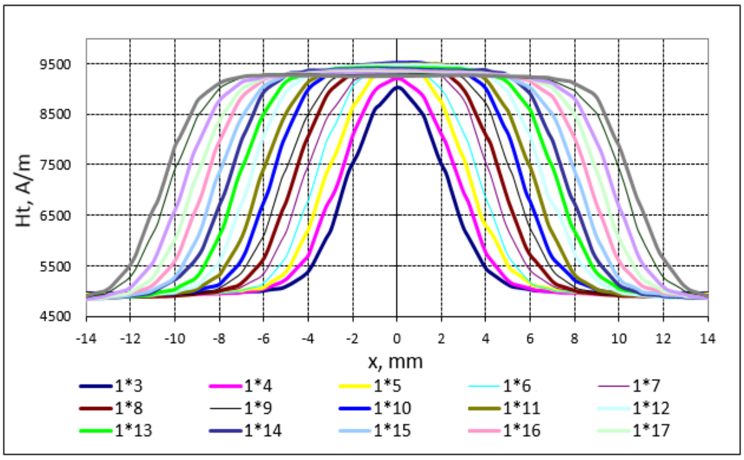

Figure 6. The horizontal plateau of the tangential component of the magnetic fields of the extended defects.

Journal of Physics: Conference Series **1389** (2019) 012037 doi:10.1088/1742-6596/1389/1/012037

3. Distinctive features of defects

A base of the magnetic fields of the above-mentioned classes of defects located at different depths and which has various orientations in the plate was created. On its basis we identified and formulated the distinctive features of three classes of defects:

- the maximum values of the tangential and normal components of the magnetic fields of surface defects are greater than these values of fields of defects of other classes;
- the tangential component of the magnetic fields of surface defects has two "humps" which become noticeable when the disclosure width of defect is more than 8% of the plate thickness;
- the tangential component of magnetic fields of longitudinal delamination defects (elongated along the x axis), the length of which is comparable to the thickness of the plate, forms a horizontal plateau;
- the normal component of magnetic fields of the extended subsurface defects has two horizontal segments;
- according to the horizontal segments of the components of the magnetic fields one can judge the extension of the defect along to x or y axis.

4. Conclusions

The topography of the fields of various types of defects was analyzed. The possibility to distinguish defects from each other depending on their classes, sizes and locations was reviewed. Recommendations for determining the classes of defects were given.

An approach for estimating the orientation of a defect in a plate was proposed. It makes possible to establish the direction of slope of a defect.

The evaluation of defects' parameters should be carried out inside the class. Depending on the material of controlled object, the class of the defect, the required accuracy and laboriousness, an effective method of calculating and evaluating the geometric parameters of the defects is chosen.

Some defects will be eliminated, some of them will be under further control, and the actions towards to the defects will differ according to the information about the classes of defects, their locations and sizes and to the safety requirements and standards.

Acknowledgments

The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (theme «Diagnostics» No. AAAA-A18-118020690196-3).

References

[1] Amineh R K , Koziel S, Nakolaeva N K, Bandler J W and Reilly J P 2008 *IEEE Trans. on Magnetics* **44** 8 2058–65
[2] Yang L,Cui W and Gao S 2015 *Testing and Measurement: Tech. and Appl*. 271–75
[3] Galchenko V Y, Ostapushchenko D L and Vorobyov M A 2009 *Rus. J. of NDT* **45** 3 191–98
[4] Dyakin V V, Kudryashova O V and Rayevskii V Ya 2018 *Rus. J. of NDT* **54** 11 765–75
[5] Novoslugina A P and Smorodinskii Ya G 2017 *Rus. J. of NDT* **53** 11 765–71
[6] Shur M L, Novoslugina A P and Smorodinskii Ya G 2013 *Rus. J. of NDT* **49** 8 465–73